Large Eddy Simulation Of Sediment Transport In The Presence Of Surface Gravity Waves, Currents And Complex Bedforms

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LONG-TERM GOAL

Our long-term goal is to employ numerical simulation to generate accurate predictions of sediment transport in the coastal zone.

OBJECTIVES

Our main focus is to build upon earlier work that produced quantitatively accurate hydrodynamics and to produce a tool for sediment transport modeling. Our tool will be a large-eddy simulation [LES] in three dimensions and time, at scales on the order of meters, and in the presence of waves and a current. In order to reach the stated goal, the hydrodynamics code will need to be changed to account for some of the sediment-fluid interactions that take place. Our numerical analysis objectives include accurate representation of the flow near rough boundaries, creation of improved models for the sub-filter scale [i.e., unresolved] motions and sediment transports, and optimization of the computer code for multiprocessor computer systems.

APPROACH

In a large-eddy simulation, the smaller scales are filtered from the equations and so the LES resolves the larger motions and transports accurately, but employs a model to describe the unresolved or subfilter-scale motions and transports. The numerical simulation code employed in our simulations (Zang, et al., 1994) solves the unsteady Navier-Stokes equations with the Boussinesq approximation and in three dimensions. An advection-diffusion equation [with a subgrid-filter closure] is used to represent suspended sediment. The subgrid-scale Reynolds stress and sediment flux are modeled with Salvetti and Banerjee's (1995) dynamic two-parameter model, in which the unknown parameters are determined dynamically over the flow domain in terms of resolved quantities. Therefore, there are no adjustable or tunable constants in this modeling scheme, which has been shown to incorporate the essential features needed for a correct subfilter-scale parameterization. These equations are discretized with second-order differences and solved with a fractional-step or projection method. We have begun with a version of the code created by Calhoun (1998) [see also Calhoun and Street, 1999] to study laboratory-scale flows over complex bedforms.

An oscillatory, periodic pressure gradient has been implemented in the code to model flow motions caused by waves. Tests of the wave-flow case are now underway over the current boundary

configurations [figures 1 & 2]. The code is also being tested for application to oscillatory flow in the presence of a current over wavy boundary configurations at small scales.

Other planned modifications to the code will account for some of the sediment-fluid interactions. Stratification effects will be included and a hindered settling velocity may be implemented. Eventually, the code may model multiple size classes of sediment.

Our major challenges involved in extending the code to field scales arise from boundary layer regions that form in the flow, e.g., in the wake of ripples. Our approach will be to examine "wall-layer" modeling strategies and to implement a new turbulence model that predicts the correct dissipation at larger scales. Katopodes & Street (1999) have developed a model that includes all of the important physics to the desired order of accuracy, and it will be tested by simulation of laboratory experiments.

Once the code has been verified for large-scale flows with rough boundaries, it can be used to model field-scale flow. We will collaborate with investigators who have conducted relevant experiments at SandyDuck and use the simulation code to simulate experimental conditions for comparison with the experimental results. We are also considering simulating experiments conducted in the Delft Oscillating Water Tunnel.

The work is being carried out by Ms. Emily A. Zedler [BS: Math, U.C., Davis; MS: CE, U.C., Berkeley]. She is a Ph.D. candidate and research assistant.

WORK COMPLETED

This project began in March 1999. A scalar transport equation in the original Calhoun code has been modified to model sediment by introduction of a settling term and a bottom boundary condition for entraining sediment, namely, van Rijn's (1994) pickup function. With these modifications, the code has been applied to two different boundary configurations (figures 1 & 2). Our strategy in the beginning has been to establish a [statistically] fully developed turbulent current and then to examine the short-term evolution of the sediment field.
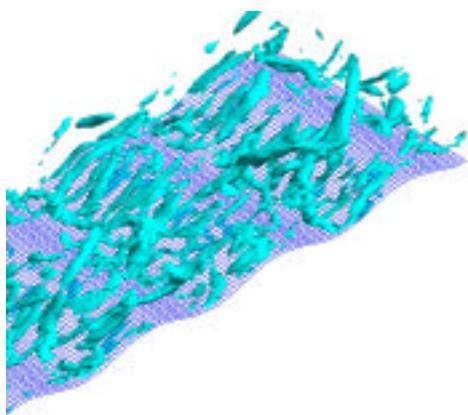

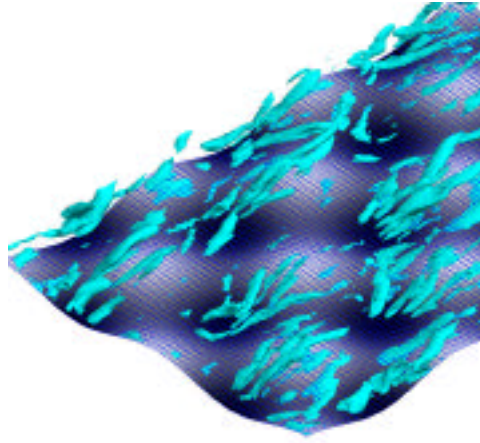*Figure 1. Streamwise vortex cores plotted over the '2D'-boundary configuration.*

Figure 2. Streamwise vortex cores plotted over the '3D'-boundary configuration.

RESULTS

In the current simulations, there is a strong coupling between the sediment and fluid motions in flows over the laboratory-scale bedforms shown in figures 1 &2. Evidence of this is found by examination of instantaneous plots of the sediment concentration with the velocity vectors superimposed on them. Over both boundary configurations, there is a clear correlation between regions where the velocity motions have a significant vertical component and the presence of sediment concentrations that are high relative to ambient values. This is pictured for the 2D domain in figure 3 on a plane perpendicular to the flow direction at a location $x/\lambda = 1.9$ [$\lambda = 5$ cm is the wavelength on the bed], just downstream of a ripple crest. Essentially, the light strip of sediment that is visible was originally entrained upstream as a strip along the upslopes of the previous ripple crest. As this horizontal strip was advected towards and over the trough, it diffused and was transported up into the flow by these vertical motions in the fluid. This strong correlation is also observed over the egg-carton-shaped boundary (figure 2), but the sediment rising events are more organized across the channel due to the spanwise bottom curvature.

The regions of the flow with significantly larger vertical velocity components are linked to the organized vortical structures that form in the flow, shown by Calhoun 1998 (see also Calhoun and Street, 1999) to be Goertler vortices that are caused by the boundary curvature. The vortices are visualized by using the Jeong-Hussain (1995) λ_2 -method, which seeks a measure of the low pressure that exists inside a vortex. These structures (figures 1 & 2) form over both boundary configurations and are linked to the transport of sediment (figure 4). Figure 4 pictures vortex cores colored by the sediment concentration which are moving into a plane perpendicular to the flow direction (so that the flow moves diagonally across the figure). The y-z components of the velocity vectors have been plotted on this plane and on the vortex cores to indicate their sense of circulation. It is clear from this figure that concentrations of sediment greater than background values are found on the vortex cores, indicating that the vortex cores may play an important role in transporting sediment higher into the flow. A similar pattern can be observed over the domain pictured in figure 3.
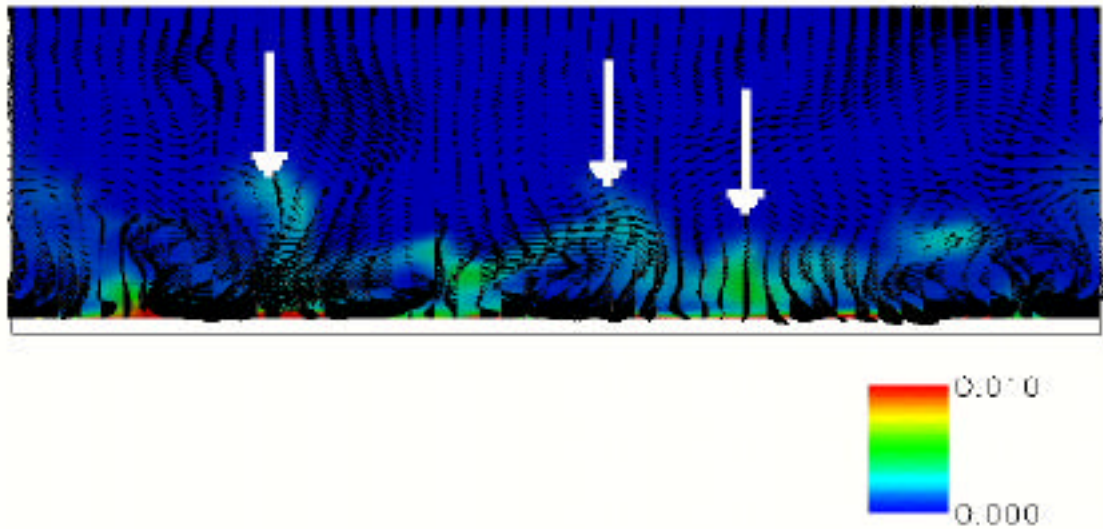
Figure 3 Velocity vectors (x-y component) are superimposed on sediment concentration contours on a cross-stream cut at x/λ = 1.9 in the '2D' flow domain. Arrows indicate events that illustrate a strong correlation between the vertical velocity component and high sediment concentrations. High concentrations are given by red, yellow, and green regions.
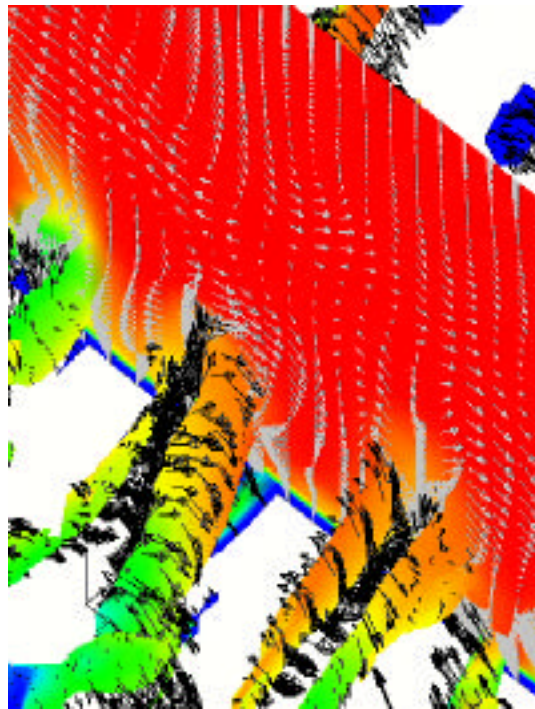

Figure 4 Iso-contours of negative $\lambda_2 = -175$ in the 2D flow domain at t = 1.2 s. The y-z velocity vectors and the concentration contours are superimposed on the iso-contours. The surface perpendicular to the flow direction is at x/λ = 2.1, just downstream of the second ripple trough. The concentration ranges from 0 (red) to 0.01 (blue). The image faces downstream.

IMPACT/APPLICATION

Recent developments in subfilter-scale modeling techniques have allowed the subfilter-scale Reynolds' stress or transport terms to be described as a function of the resolved-scale velocities [so-called velocity estimation models]. These models have no adjustable or tunable constants that must be set *a priori*. Furthermore, large-eddy simulations calculate the time evolution of the resolved motions that form in the flow and are an important tool for studying the relationship between sediment transport patterns and coherent structures, such as bursts and sweeps that form in the flow. However, there are clearly many aspects of extending large-eddy simulations to larger scales that need to be examined. Therefore, the intent of this research is to extend our large-eddy simulation code to larger scales to study the detailed physics of sediment transport. The ultimate results of this study should both illustrate the importance of coherent structures on sediment transport and identify the limiting boundaries of large-eddy simulation codes.

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